Enhancing Lithography Process Control Through Advanced, On-board Beam Parameter Metrology for Wafer Level Monitoring of Light Source Parameters

Jinphil Choi[a], Nakgeuon Seong[b], Omar Zurita[b], Joshua Thornes[b], Yookeun Won[b], Slava Rokitski[b], Youngseog Kang[a], Bernd Burfeindt[b], Chanhoon Park[a]
[a]Samsung Electronics Co, San #16 Banwol-Dong, Hwasung-City, Gyeonggi-Do;
[b]Cymer Inc., 17075 Thornmint Court, San Diego, CA, 92127, USA

ABSTRACT

In order to improve process control of the lithography process, enhanced On-board metrology, measuring of the light source beam parameters with software solutions for monitoring, reporting and analyzing the light source's performance has been introduced.

Multiple lasers in the field were monitored after installing of a new On-board metrology product called SmartPulse. It was found that changes in beam parameters can be significantly reduced at major module change service events when new service procedures and On-board metrology were used, while significant beam parameter shift and illumination pupil changes were observed when On-board metrology was not available at service events, causing lengthy scanner illumination pupil recalibration.

SmartPulse™ software from Cymer Inc. was used to monitor the variation of light source performance parameters, including critical beam parameters, at wafer level resolution. Wafer CD was correlated to the recorded beam parameters for about a month of operation, and both wafer CD and beam parameters showed stable performance when the light source was operating at optimal conditions.

Keywords: Photo-lithography, On-board metrology, Laser beam parameter, Light source performance parameter monitoring

1. INTRODUCTION

The monitoring and control of process parameters at the process tool level has been used to improve process stability without increasing direct off-line wafer metrology, enabling fast wafer turn-around time and fab capital cost reduction[1] . The need to provide process monitoring capability with higher resolution and additional process parameters at the light source level has been observed.

1.1 Process monitoring and control improvement

As the use of ArF immersion lithography processes for most critical layer patterning has continued for multiple technology generations, each lithographic imaging solution has become highly optimized for specific patterns to be printed. Use of different imaging solutions for different device patterns also drives different levels of control for process variables. For example, highly optimized SMO(source mask optimization) imaging solutions require tighter control of the illumination pupil than simple SDP (Spacer double pattering) with dipole illumination. Very high throughput lithography patterning processes were implemented to reduce the cost of multiple patterning processes, which are commonly used for memory device production. It has been recognized that smaller pattern size and lower k1 imaging processes at the latest technology nodes drive tighter control of more process performance parameters of lithography tools than at previous nodes. Process parameter monitoring and control for the process tools has been adopted as a way of reducing process errors and improving process control, and minimizing added metrology capital costs.(Figure 1.)

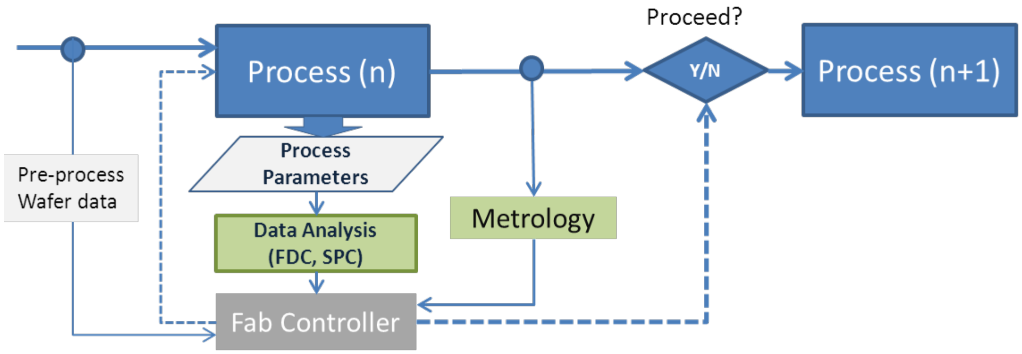

Figure 1. Concept diagram of process control utilizing equipment process parameters

1.2 Laser parameter monitoring

Light sources for lithography have previously relied on three major metrics to determine if the quality of the light produced meets requirements for wafer production: center wavelength, bandwidth and energy. The importance of monitoring and controlling light source bandwidth was previously reported on various papers[2,3,4] and improvements to the laser were delivered over time[5]. Lately a software solution has been developed for improved monitoring, reporting and analysis capabilities. The software correlates laser optical parameters, such as bandwidth, wavelength and energy, to the wafer level.

In addition to the optical parameters of the light source, the need for beam parameter monitoring and control was recognized when noticeable changes of illumination pupil images were sometimes reported after laser service events requiring laser beam alignment(Figure 2.) Illumination pupil changes can induce changes of wafer CD, which is a significant issue for current lithography processes since the stability of the illumination pupil is one of the most critical parameters for OPC (optical proximity correction) stability. When an illumination pupil change was observed, it triggered, in most cases, a lengthy scanner illumination recalibration process, which can cause several hours of production down time. In general, laser beam parameters are measured and characterized with off-line field service tools after the laser service events. Off-line beam metrology does not provide beam parameter information before the service event, and cannot provide real-time information during normal operation of the laser. Therefore new On-board metrology was developed to enable real-time measurement of beam parameters with high accuracy and with a fixed reference point.

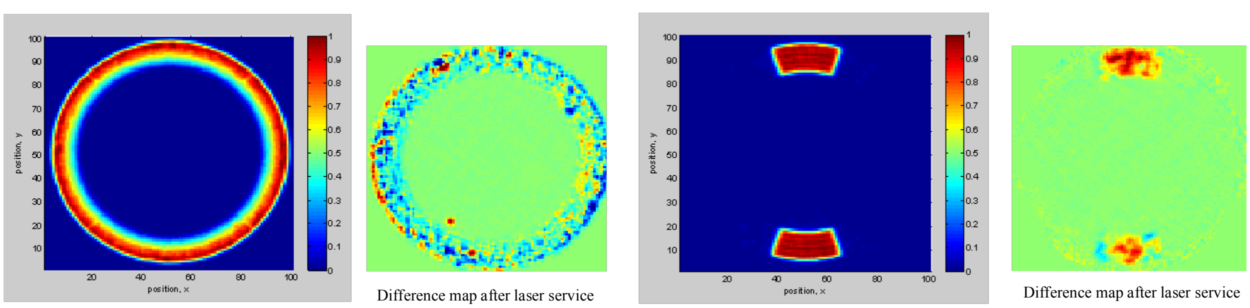

Figure 2. Two examples of illumination pupil change after laser service events

2. ON-BOARD LASER METROLOGY

Advanced, On-board beam parameter metrology is offered as an upgrade to Cymer's industry leading XL light source platform. This upgrade adds new capability to the platform by providing a new metrology system with significantly expanded in-situ metrology capabilities. This expands the existing metrology on the XL

platform to make available to the chipmaker beam parameter measurements in addition to the already available data on energy, wavelength and bandwidth.

The first of these new capabilities is in-situ 2D imaging of the light source beam. This system obtains both near-field and far-field images of the light source (Figure 3) simultaneously. These images are used both qualitatively to provide additional information about the light source and quantitatively to derive standard beam parameter metrics, such as divergence and energy density. The On-board beam parameter metrology also includes pointing measurements which are absolutely referenced to the interface between scanner and light source. Lastly, polarization ratio is also constantly measured by the metrology unit.

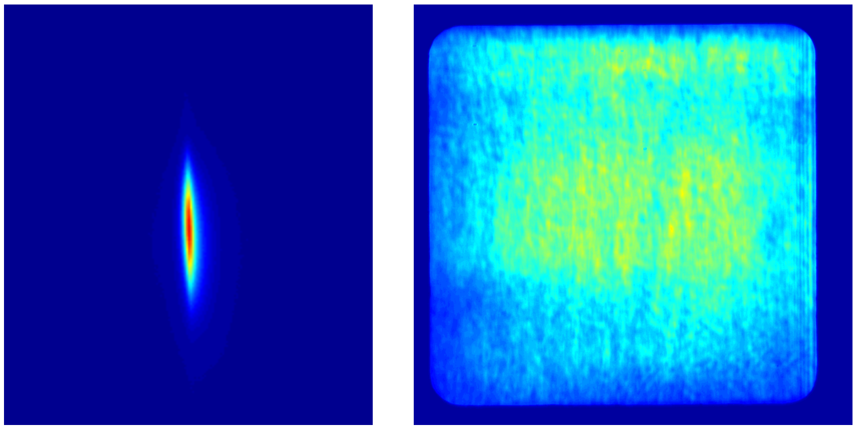

Figure 3: Color image of farfield (left) and nearfield (right) of XL light source obtained with On-board Beam Metrology

The On-board local controller processes data from the metrology unit into high resolution data that characterizes the light source performance. This data can be monitored by chipmakers to understand potential wafer variability. Furthermore, the data can be remotely accessed via CymerOnLine® connectivity solution to monitor the health of the laser thereby improving the accuracy of service event prediction.

Cymer's new light source parameter monitoring software , SmartPulse™, was developed for efficient monitoring of light source performance parameters with built in statistical analysis and warning capabilities. It performs data monitoring, reporting and analysis of light source performance parameters including the new On-board beam parameter metrology data.(Figure 4) It provides wafer level resolution data enabling direct correlation of wafer performance to light source parameters to support improved process control and yield. The product is also capable of alarming for any excursion of the monitored parameters from preset limits.

One data per wafer (collected during wafer exposure)	
BQ data (8)	**Onboard Metrology data (7)**
E95 bandwidth average	Divergence X
E95 bandwidth target	Divergence Y
FWHM bandwidth average	Pointing X
Energy average	Pointing Y
Energy sigma	Beam size X
Wavelength sigma	Beam size Y
Wavelength target	Energy density
Time stamp	

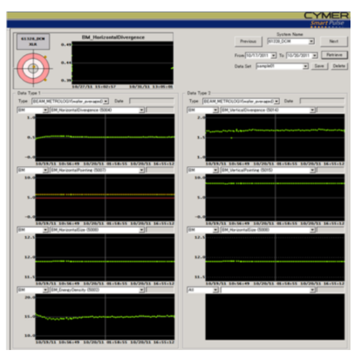

Figure 4: Software solution, SmartPulse, provide monitoring, reporting and analysis capabilities of light source parameters in wafer level resolution

3. FIELD APPLICATION DATA OF ON-BOARD METROLOGY

3.1 Analysis of monitored data

Multiple On-board metrology modules were installed in the field and monitored for several months.

Long term drift of all beam parameters was minimal and local variation depended on the operation conditions of each tool, due to product type and tool utilization. The local variation was reduced after laser modules were replaced and the laser performance optimized. In general the scale of local variation was within an acceptable range compared to control requirements. In one case, a significant shift of vertical pointing was observed on a tool after a module exchange service and the shift exceeding the allowed limit value. It would not have been recognized if the new On-board beam parameter metrology had not been installed on the tool (Figure 5). Total variation of beam parameters can be maintained well within control requirements if any shift at service events is reduced by using the new On-board beam parameter metrology for continuous beam parameter monitoring to a fixed reference point.

When the measured data was filtered for 30 to 40 percent duty cycle operation, which represents typical wafer exposure operation, excluding maintenance and calibration events, the local variation was reduced by about 40% (Figure 6). SmartPulse captures light source performance parameters during wafer exposure operation only to maximize the correlation of wafer CD performance to recorded light source performance parameters.

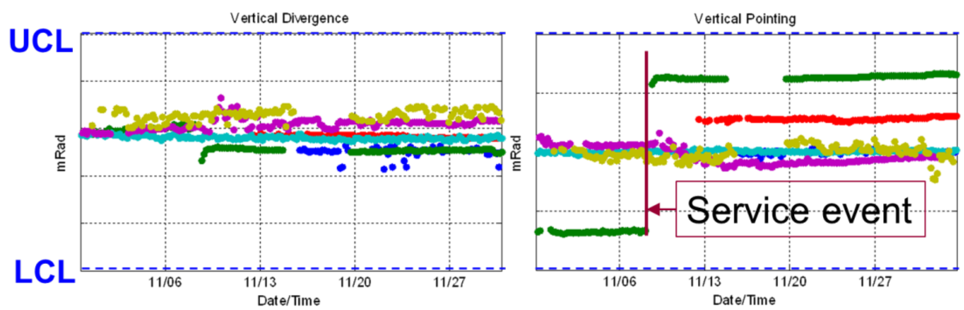

Figure 5: Long term (one month) data of measured beam parameters from six field installed tools

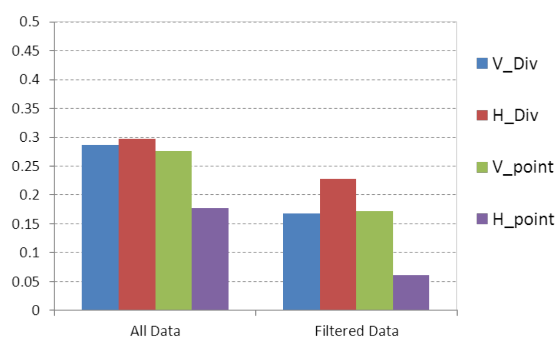

Figure 6: Local variation of measured beam parameters against control target. Before and after was referenced to laser module service event. Filtering applied to select only measurements at 30 to 40 percent duty cycle.

Two service events were compared to understand the impact of service on beam parameters. At Service A in Figure 7, no attempt was made to use measured On-board beam parameter metrology and resulted in unacceptable shifts in one beam parameter (vertical pointing). A shift in the illumination pupil was also confirmed. When an improved procedure was used with the new On-board beam parameter metrology tool,

the change in the beam parameter was minimized to within normal local variation levels (Service B at Figure 7.) The results showed that the change in light source beam parameters during light source service events can be significantly reduced by using the new On-board beam parameter metrology tool and an improved service procedure. The reduced change of beam parameter at each service event will minimize the change of illumination pupil, with the possibility of reducing required scanner illumination recalibration procedure, resulting in improved lithography tool availability for wafer production.

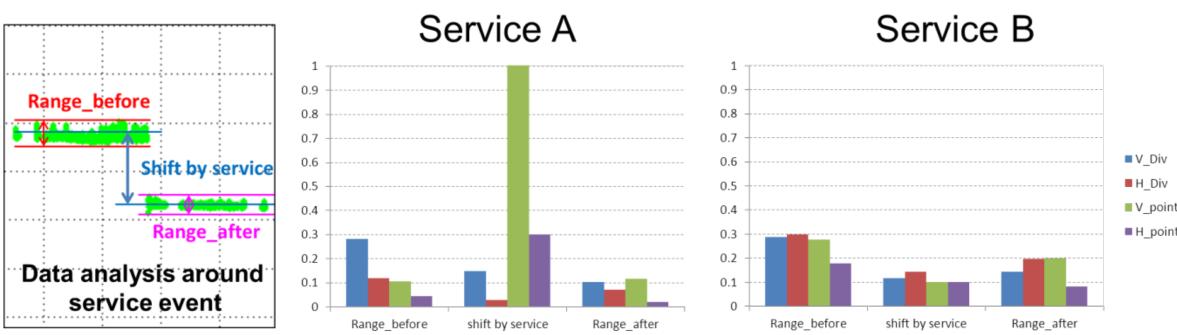

Figure 7: Comparison of beam parameter variation surrounding laser service events.

3.2 Correlation with measured wafer CD data

Resist CDs were measured from wafers processed on a tool which had On-board beam parameter metrology installed. An attempt was made to correlate measured CD data with measured beam parameters during wafer exposure of the wafer. To understand any dependence on the illumination pupil, wafers from two layers having different type of illumination were measured and analyzed. There was no noticeable drift of both beam parameters and wafer CDs since the light source performance was in a optimal condition. All were well within control limit for the one month of the monitoring period and monitoring is ongoing. (Figure 8.)

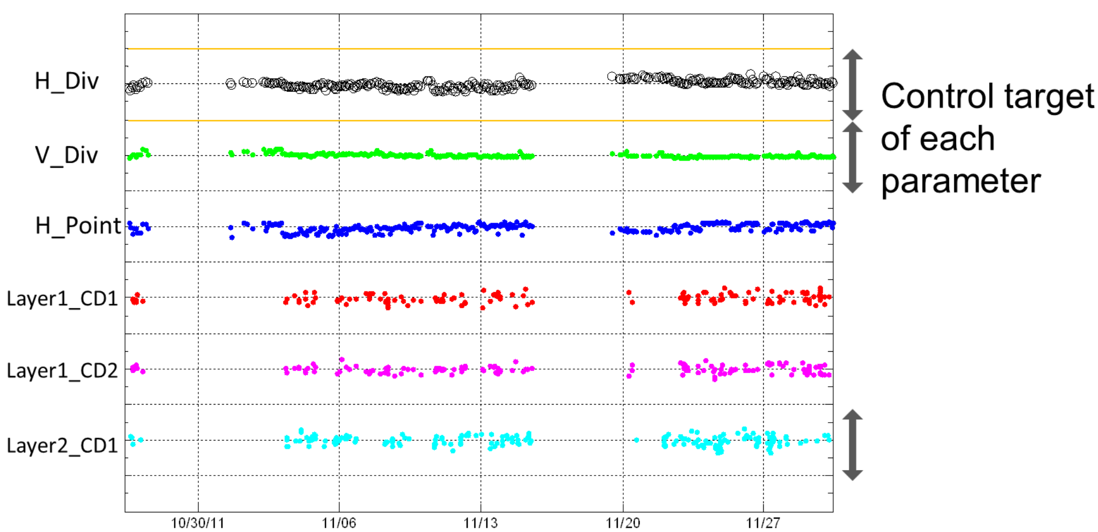

Figure 8: Comparison of beam parameter variation surrounding laser service event.

4. SUMMARY

A new On-board metrology module, which measures beam parameters of the light source in real-time, and SmartPulse light source parameter monitoring software, were introduced by Cymer to improve process stability, especially proximity effect for OPC stability.

Real-time monitoring of light source performance parameters during wafer exposures will enable a correlation with CD performance on the wafers as well as laser health status.

The new On-board beam parameter metrology can be used to minimize the change of beam parameters to avoid lengthy illuminator pupil calibration after light source service by using an improved service procedure.

Stable CD performance was observed with stable beam parameter performance of optimal laser operation.

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